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3 TITLE OF THE INVENTION (200 characters or spaces maximum)

Process for fabricating a microstructure containing a vacuum cavity, and corresponding microstructure

4 PRIORITY DECLARATION OR APPLICATION FOR THE BENEFIT OF THE FILING DATE OF A PRIOR FRENCH APPLICATION

Country or organisation

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PATENT

UTILITY CERTIFICATE

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The inventors are the applicants

☐ Yes☒ No In this case, provide a separate designation of the inventor(s)**8 SEARCH REPORT**

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Process for fabricating a microstructure containing a vacuum cavity, and corresponding microstructure

The subject of the invention is a process for
5 fabricating a microstructure containing a vacuum cavity.

The subject of the invention is also a microstructure containing a vacuum cavity.

10

The field of the invention is that of components comprising a microstructure containing an internal cavity placed under vacuum. Among such components, mention may be made of sensors for detecting various
15 physical parameters, such as pressure sensors, acceleration sensors or angular velocity sensors, such as gyroscopes.

The function of the cavity may be to:

20

- form a vacuum reference cavity for pressure sensors;

- allow the vacuum packaging of sensor elements such as resonators widely used to produce resonant pressure sensors, resonant accelerometers or VBAs
25 (vibrating beam accelerometers), vibrating gyroscopes or electromechanical filters.

The performance characteristics of such components, and especially precision and stability depend in particular
30 on the vacuum achieved in the cavity, that is to say the internal pressure of the cavity: good performance characteristics are obtained when these components operate at very low pressure, typically less than 0.01 mbar.

35

For example in the case of components using resonators, it is necessary to ensure a low enough pressure level around the resonator (between 0.0001 and 0.01 mbar, in

order to avoid introducing damping into the movements of the resonator.

5 In the case of accelerometers, operation at these very low pressures also prevents, although the cavity is placed in a vacuum, the residual gas in the cavity from disturbing the operation by modifying the reference mass value of the accelerometer by an absorption/desorption effect of the molecules on the
10 surface of the mass.

Various types of technology for evacuating the cavity may be used.

15 A first technology consists in producing a metal or ceramic package in which the microstructure is placed, the cavity of which is left open. The package is then evacuated by pumping/outgasing the cavity by means of an exhaust tube (for example made of glass) for several
20 days; the package is then sealed by a tube tipping-off operation, that is to say by pinching off the tube. The major drawbacks of this technology are cost and the size of the package.

25 A second technology, which relates only to the microstructure, consists in providing a small hole in a dedicated region of the cavity. Figure 1 shows an example of such a microstructure 1, the cavity 2 of which is bounded by three wafers, an upper wafer 3, a
30 lower wafer 4 and an intermediate wafer 5; a resonator 6 housed in the cavity 2 is used to measure the pressure by means of a membrane 7 to which it is connected. The microstructure conventionally has contact pads 10 and optionally insulating layers 11.

35 After pumping down/outgasing the cavity 2, the hole 8 is sealed off by fusion of a suitable material 9, such as a glass or a metal alloy, for example Sn/Pb.

The sealing-off operation is carried out microstructure by microstructure, and requires preparation of the surfaces of the hole in order to permit the sealing material to adhere to these surfaces, which represents
5 a first drawback of an industrial kind.

There is also a technical drawback associated with the presence of a sealing material that differs from the base material of these microstructures, generally
10 silicon or even quartz. This inhomogeneity between the materials introduces high stresses on the walls of the hole because of the differential expansion between these materials: for example, the expansion of silicon is from 2 to 3 ppm/°C whereas that of an Sn/Pb alloy
15 exceeds 15 ppm/°C. The stresses generated may then be transferred to the active part of the microstructure and degrade the measurement performance.

The above technologies apply when the cavity has been
20 formed.

A third technology, which also relates only to the microstructure, comes into play during production of the cavity: it consists in joining together, under
25 vacuum, wafers that define the cavity. The joining operation is carried out by bonding, namely glass/silicon anodic bonding when one wafer is made of glass and the other made of silicon, and silicon/silicon bonding when both wafers are made of
30 silicon.

In the case of glass/silicon bonding, the bonding process causes oxygen to be produced by decomposition of the glass used for this type of bonding; this may be
35 the glass of the wafer itself or of a glass used for the bonding, and identical to the glass of the wafer. Such oxygen production results in an internal pressure

of 1 to 10 mbar, which is much too high for the intended components.

- 5 Silicon/silicon bonding makes it possible to produce a homogeneous microstructure of excellent mechanical quality and hermeticity. A physico-chemical treatment of the substrates is carried out in order to place the surfaces to be bonded in a particular chemical state. Moreover, the bonding process must be supplemented with
- 10 a heat treatment at high temperature, typically 1000°C, in order to achieve optimum properties of the join. To avoid a substantial rise in pressure caused by the heat treatment, a prior operation of outgasing the walls of the cavity ought to be carried out; however, this
- 15 outgasing operation would then destroy the chemical state of the surfaces to be bonded. This technology therefore does not make it possible to obtain a low pressure inside the cavity.
- 20 Another technology consists in providing in the cavity an additional location intended to accommodate a getter material that can absorb the residual gases in the cavity. It supplements, for example, the third technology. This additional location increases the
- 25 volume of the microstructure. Moreover, it requires the getter material to be fixed to one of the walls of the cavity, which introduces an additional step in the fabrication process. Finally, the operation of fixing the getter to the wall must be compatible with an
- 30 annealing operation, when such an operation is necessary, via a heat treatment such as that described in the case of the previous technology, thereby introducing an additional constraint.
- 35 One important object of the invention is therefore to propose a process for fabricating a microstructure containing a vacuum cavity that does not have the abovementioned drawbacks.

To achieve this object, the invention proposes a process for fabricating a microstructure containing a vacuum cavity, mainly characterized in that it
5 comprises the following steps that consist in:

a) producing, in the thickness of a first silicon wafer, a porous silicon region intended to form, completely or partly, one wall of the cavity and capable of absorbing residual gases in the cavity;

10 b) joining the first silicon wafer to a second wafer, so as to produce the cavity.

According to one feature of the invention, the joining operation of step b) is carried out under vacuum,
15 especially by bonding at ambient temperature.

The process according to the invention, which consists in directly evacuating the cavity during assembly of the wafers that define the cavity, is thus based on the
20 use of a material that can absorb the residual gases in the cavity. This material is formed from one of the wafers and therefore has the same mechanical properties as the rest of the microstructure.

25 The subject of the invention is also a process for the collective fabrication of microstructures.

The invention also relates to a microstructure containing a vacuum cavity, characterized in that it
30 comprises at least two wafers that contribute to defining the cavity, one of said wafers being made of silicon and including a porous silicon region capable of absorbing residual gases in the cavity, the region being produced in the thickness of said silicon wafer.

35

Finally, the invention relates to a sensor having such a microstructure.

Other features and advantages of the invention will become apparent on reading the detailed description that follows, given by way of nonlimiting example and with reference to the appended drawings in which:

5 - figure 1, already described, shows schematically a microstructure used for a pressure sensor;

10 - figure 2 shows schematically a microstructure according to the invention, again used for a pressure sensor.

The process according to the invention will now be described in greater detail by taking as example the fabrication of a microstructure for a pressure sensor
15 of the same type as that of Figure 1, the cavity of which is bounded by three wafers. The microstructure obtained is shown in Figure 2; the same elements are denoted by the same references.

20 One of the wafers, in this case the upper wafer 3, is made of silicon, preferably single-crystal silicon; according to a first step of the invention, a porous silicon region 31 is produced from this wafer 3, in the thickness of the latter.

25 This porous silicon region is in general produced using methods known to those skilled in the art, by electrochemical etching in a solution based on hydrofluoric acid to which H_2SO_4 or HNO_3 or ethanol has
30 been added. Depending on the method used, the porous silicon obtained has a percentage void content of 30 to 60%, with pores from 20 to 40 ångströms in the case of an n-or p⁻-type silicon substrate, or pores of 0.1 μm in the case of a p⁺-type substrate. These pores are as
35 many microcavities, generating a very large absorption surface compared with the initial surface area of the substrate.

This porous silicon region can be produced over very substantial thicknesses, typically between 100 and 200 μm ; it retains the same volume and the same thermal expansion coefficient as single-crystal silicon. The
5 silicon wafer that includes this porous silicon region thus remains homogeneous from the thermal standpoint.

This region fabricated from the wafer itself is thus rendered more fully integral with the upper wafer than
10 if it had been added to this wafer and fixed thereto; it consequently exhibits better resistance to the mechanical vibrations to which the microstructure may be subjected in the course of operation.

15 According to a variant of the invention, another material that can also absorb the residual gases in the cavity is deposited by spraying on the porous silicon region, in proportions allowing the pores of the porous silicon to be covered without however blocking them.
20 The porous silicon region thus impregnated is used in this case solely to increase the absorption surface area in the cavity. This other material, chosen to be more active than porous silicon, may be titanium.

25 During a second step, the wafers 3, 4 and 5 undergo a physico-chemical preparation of their surface for the purpose of joining them together - the surfaces are, for example, prepared by means of concentrated nitric acid solution which causes OH radicals to be generated
30 on the surface of the wafers.

The wafers 3, 4 and 5 are then outgased; the outgasing is however limited in order not to destroy the physico-chemical state of the surfaces that was
35 obtained after the previous step.

The wafers are then joined together under vacuum, by bonding at ambient temperature, or possibly by brazing

at temperatures varying up to about 400°C. Firstly, the lower wafer is, for example, joined to the intermediate wafer and the resonator fastened to the lower wafer; the upper wafer is then joined to the intermediate
5 wafer. The intermediate wafer, upper wafer and resonator may also be made of silicon, or even glass or a combination of silicon and glass.

The microstructure thus obtained is subjected to a
10 high-temperature annealing operation (between 400 and 1000°C) in order to strengthen the bond. Porous silicon has the advantage of being compatible with these temperatures. During this annealing phase, the internal surfaces undergo strong outgasing, typically resulting
15 in an increase in pressure from 10 to 100 mbar in the absence of porous silicon. The presence of a large surface area of porous silicon makes it possible, however, during this annealing phase to absorb the molecules responsible for the increase in pressure and
20 to bring the cavity back to a high vacuum, of 0.01 millibar or less.

During this annealing, there also occurs an activation of the porous silicon that generally takes place at
25 temperatures of around 400°C. This activation allows the surface of the porous silicon to be cleaned by desorption of the H molecules present after production of the porous silicon layer.

30 Thereafter, during operation of the microstructure, outgasing also occurs, to a lesser extent than that occurring for example during the annealing phase, but nevertheless of nonzero extent. The amount of porous silicon is in general sufficient to absorb the
35 molecules resulting from this slight outgasing. As a result, the stability and reliability of the microstructure during operation are improved. The lifetime of such a microstructure is commonly 20 years.

In the microstructure example described, the cavity is bounded by three wafers. In another example, the cavity may be bounded by two wafers, one or both of which have an indentation.

A microstructure for a pressure sensor has been described, but the process according to the invention makes it possible, of course, to fabricate microstructures for high-precision sensors that in general make use of the resonant elements, or to fabricate microstructures for devices other than sensors.

This fabrication process furthermore makes it possible to produce microstructures, such as those described, collectively by full-wafer assembly. This is because no hole-sealing-off operation needs to be carried out microstructure by microstructure.

CLAIMS

1. A process for fabricating a microstructure containing a vacuum cavity, characterized in that it
5 comprises the following steps that consist in:

- a) producing, in the thickness of a first silicon wafer, a porous silicon region intended to form, completely or partly, one wall of the cavity and capable of absorbing residual gases in the cavity;
10 b) joining the first silicon wafer to a second wafer, so as to produce the cavity.

2. The process as claimed in the preceding claim, characterized in that step a) furthermore includes a
15 step consisting in impregnating the porous silicon region with another material that can also absorb residual gases in the cavity.

3. The process as claimed in either of the preceding
20 claims, characterized in that, when the cavity has a predetermined height, the joining operation of step b) is carried out by means of an intermediate wafer whose thickness contributes to the height of the cavity.

25 4. The process as claimed in any one of the preceding claims, characterized in that, prior to step b), it includes a step consisting in carrying out a physico-chemical preparation of the surfaces of the wafers used in step b).

30 5. The process as claimed in any one of the preceding claims, characterized in that, prior to step b), it includes a step consisting in outgasing the wafers used in step b).

35 6. The process as claimed in any one of the preceding claims, characterized in that the joining operation of step b) is carried out under vacuum.

7. The process as claimed in the preceding claim, characterized in that the joining operation is carried out by bonding at ambient temperature.

5

8. The process as claimed in the preceding claim, characterized in that it includes a step c) consisting in annealing, at between 400 and 1000°C, the microstructure obtained after step b) so as to
10 strengthen the bond.

9. The process as claimed in any one of Claims 2 to 8, characterized in that the other material that can also absorb the residual gases in the cavity consists
15 of titanium.

10. The process as claimed in any one of the preceding claims, characterized in that the second wafer and/or the intermediate wafer are made of silicon or glass.

20

11. The process for collectively fabricating microstructures as claimed in any one of the preceding claims.

25 12. A microstructure containing a vacuum cavity, characterized in that it comprises at least two wafers that contribute to defining the cavity, one of said wafers, called the first wafer, being made of silicon and including a porous silicon region capable of
30 absorbing residual gases in the cavity, the region being produced in the thickness of said silicon wafer.

13. The microstructure as claimed in the preceding claim, characterized in that the porous silicon region
35 is impregnated with another material that can also absorb residual gases in the cavity.

14. The microstructure as claimed in the preceding claim, characterized in that the other material that can also absorb residual gases in the cavity is titanium.

5

15. The microstructure as claimed in any one of claims 12 to 14, characterized in that the wafers other than the first wafer are made of silicon or glass, or a combination of silicon and glass.

10

16. The microstructure as claimed in any one of claims 12 to 15, characterized in that it includes a resonator housed in the cavity.

15 17. A sensor having a microstructure as claimed in any one of claims 12 to 16.

18. The sensor as claimed in the preceding claim, characterized in that the sensor is a resonant pressure sensor or a resonator accelerometer or a vibrating gyroscope or an electromechanical filter.

20

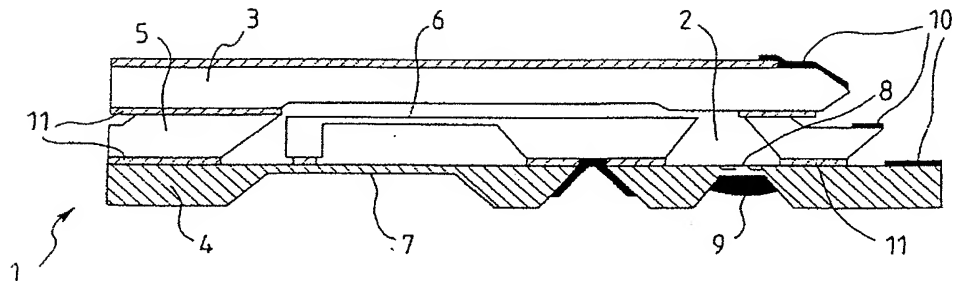


FIG.1

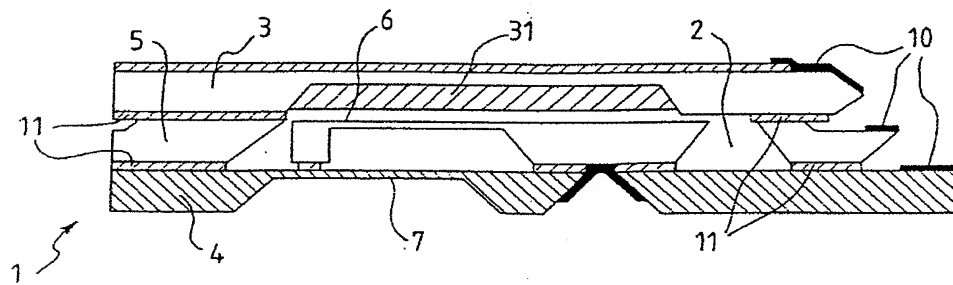


FIG.2

CLAIMS

1. A process for fabricating a microstructure containing a vacuum cavity, characterized in that it
5 comprises the following steps that consist in:

a) producing, in the thickness of a first silicon wafer, a porous silicon region intended to form, completely or partly, one wall of the cavity and capable of absorbing residual gases in the cavity;

10 b) joining the first silicon wafer to a second wafer, so as to produce the cavity.

2. The process as claimed in the preceding claim, characterized in that step a) furthermore includes a
15 step consisting in impregnating the porous silicon region with another material that can also absorb residual gases in the cavity.

3. The process as claimed in either of the preceding
20 claims, characterized in that, when the cavity has a predetermined height, the joining operation of step b) is carried out by means of an intermediate wafer whose thickness contributes to the height of the cavity.

25 4. The process as claimed in any one of the preceding claims, characterized in that, prior to step b), it includes a step consisting in carrying out a physico-chemical preparation of the surfaces of the wafers used in step b).

30 5. The process as claimed in any one of the preceding claims, characterized in that, prior to step b), it includes a step consisting in outgasing the wafers used in step b).

35 6. The process as claimed in any one of the preceding claims, characterized in that the joining operation of step b) is carried out under vacuum.

7. The process as claimed in the preceding claim, characterized in that the joining operation is carried out by bonding at ambient temperature.

5

8. The process as claimed in the preceding claim, characterized in that it includes a step c) consisting in annealing, at between 400 and 1000°C, the microstructure obtained after step b) so as to
10 strengthen the bond.

9. The process as claimed in any one of Claims 2 to 8, characterized in that the other material that can also absorb the residual gases in the cavity consists
15 of titanium.

10. The process as claimed in any one of the preceding claims, characterized in that the second wafer and/or the intermediate wafer are made of silicon or glass.

20

11. The process as claimed in any one of the preceding claims, characterized in that it is applied collectively to several microstructures.

25 12. A microstructure containing a vacuum cavity, characterized in that it comprises at least two wafers that contribute to defining the cavity, one of said wafers, called the first wafer, being made of silicon and including a porous silicon region capable of
30 absorbing residual gases in the cavity, the region being produced in the thickness of said silicon wafer.

13. The microstructure as claimed in the preceding claim, characterized in that the porous silicon region
35 is impregnated with another material that can also absorb residual gases in the cavity.

14. The microstructure as claimed in the preceding claim, characterized in that the other material that can also absorb residual gases in the cavity is titanium.

5

15. The microstructure as claimed in any one of claims 12 to 14, characterized in that the wafers other than the first wafer are made of silicon or glass, or a combination of silicon and glass.

10

16. The microstructure as claimed in any one of claims 12 to 15, characterized in that it includes a resonator housed in the cavity.

15 17. A sensor having a microstructure as claimed in any one of claims 12 to 16..

18. The sensor as claimed in the preceding claim, characterized in that the sensor is a resonant pressure
20 sensor or a resonator accelerometer or a vibrating gyroscope or an electromechanical filter.

**PATENT****UTILITY CERTIFICATE**

Intellectual Property Code - Book VI

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DESIGNATION OF THE INVENTOR(S) Page No. . 1 . / . 1
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THE APPLICANT(S): THALES			
DESIGNATE(S) AS INVENTOR(S): (Indicate top right "Page 1/1". If there are more than 3 inventors, use an identical form and number each page, indicating the total number of pages.)			
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